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Rhizome Anatomy in *Atractylodes koreana* and *A. japonica* (Compositae), Original Plants of Chinese Natural Medicine "Cangzhu" and "Baizhu"

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Rhizomes of *Atractylodes koreana* and *A. japonica* were anatomically examined, with special reference to diameter of oil cavities, the number of oil cavities per mm^2, ratio of oil cavity area to transection area, ratio of xylem fiber area to xylem area, ratio of rhizomes with phloem fibers to total number of rhizomes in sample, and ratio of rhizomes with cotton-like crystals of hinesol and β-eudesmol to total number of rhizomes in sample. Comparisons of the anatomical features mentioned above were made among the four species; *A. koreana*, *A. japonica*, *A. lancea* and *A. chinensis*. The rhizome anatomy of the latter two species was reported separately (Terabayashi et al 1997). *Atractylodes koreana* and *A. japonica* are very similar to each other but differ from *A. lancea* in anatomical features of the rhizomes in having smaller oil cavities, much more xylem and phloem fibers, and no cotton-like crystals of hinesol and β-eudesmol. *Atractylodes chinensis* is very similar in rhizome anatomy to *A. koreana* and *A. japonica*, but differs only in the lower ratio of rhizomes with phloem fibers to total number of rhizomes in sample.

Key words: anatomy, *Atractylodes koreana*, *Atractylodes japonica*, rhizome.

The Chinese natural medicines Cangzhu and Baizhu are prepared from the rhizomes of *Atractylodes* species. For reliable identification of them, it is highly necessary to make clear anatomical features of rhizomes of *Atractylodes* species. In a previous report we revealed that *A. lancea* was diverse morphologically and chemotaxonomically and three groups were recognized in this species (Miki et al. 1993a, 1993b, Takeda et al. 1994, 1995a, 1995b, 1996, Terabayashi 1997). These three groups of *A. lancea* and *A. chinensis* were different from each other in the morphology of aerial parts, the rhizome anatomy, and the contents of essential oil components in rhizomes. In this article the three groups of *A. lancea* are tentatively named as *A. lancea* G1, *A. lancea* G2 and *A. lancea* G3, respectively. The former two will be described as new taxa in a separate paper by Miki, one of the present authors.

The rhizomes of *A. koreana* and *A. japonica* are also collected for medicinal use, under the name of Cangzhu in China (Institute of Materia Medica, Chinese Academy of Medicinal Sciences et al (eds.) 1979, Zhu You-Chang ed. 1989). In Japan the rhizomes of *A. japonica* are imported

from China and Korea as natural medicine too but named as Baizhu (Committee for editing of the commentaries on Japan Pharmacopoeia 2001).

The rhizome anatomy of *A. koreana* and *A. japonica* was described previously (Institute of Materia Medica, Chinese Academy of Medicinal Sciences et al. (ed.) 1979, Takahashi and Maruyama 1961, Takahashi and Namba 1961). However, these reports were based on limited samples. For a correct identification, it is needed to understand fully the variation of rhizome anatomy for each species.

The aim of this article is to describe anatomical characteristics of the rhizome of *A. koreana* and *A. japonica* in detail, with special reference to the oil cavity, phloem and xylem fibers and cotton-like crystals of hinesol and β-eudesmol in transections, using many samples collected in various localities. Comparisons of anatomical features mentioned above were made among the four species, *A. koreana*, *A. japonica*, *A. lancea* and *A. chinensis*. We used the data for *A. lancea* and *A. chinensis*, which were given in the previous report (Terabayashi et al. 1997).

Atractylodes ovata (=*A. macrocephala*), the rhizomes of which are also used as a natural medicine, Baizhu, is not treated in

Table 1. Collection data of *Atractylodes* species examined in this study

Species	Locality	Collecting Date	No. of ind. investigated	Voucher No.
Atractylodes koreana				
	Saxiangguoyuan, Nanfeng, Kunyushanling, Muping-xian, Shandong Prov., China (中国山東省牟平県混愈山林場三郷果園南峯)	1992.9.14	10	36374
	Huangjiayuan, Kunyu, Shanlinchang, Muping-xian, Shandong Prov., China (中国山東省牟平県混愈山林場黄家園)	1992.9.14	10	36275
	Bianmen-xiang, Fengcheng-xian, Liaoning Prov., China (中国遼寧省鳳城県辺門郷)	1993.10.6	8	41395
Atractylodes japonica				
	Wuyougou, Baihua-xiang, Jiagedaji, Neimenggu Zizhiqu., China (中国内蒙古加達奇市白樺郷五叉溝)	1995.8.23	6	39070
	Helinchang, Dailiangzi, Tangyuan-xian, Heilongjiang Prov., China (中国黒竜江省湯原県大亮子河林場)	1997.7.25	10	40398
	Linchang, Shengli, Hengshanqu, Jixi, Heilongjiang Prov., China (中国黒竜江省鶏西市恒山区勝利林場)	1994.9.5	10	38124
	Xidaiyao-zhen, Dengta-xian, Liaoning Prov., China (中国遼寧省灯塔県西大窯鎮)	1996.8.30	10	39499
	Mt. Pukansan, Seoul, Korea (韓国ソウル北漢山)	1994.9.29	5	39187
	Ulchin-gun, Kyongsangbuk-do, Korea (韓国慶北道尉珍郡)	1994.10.28	8	39186
	Mt. Fubo, Shiroishi, Miyagi Pref., Japan (宮城県白石市不忘山)	1993.11.11	6	12967
	Ryozen, Date-gun, Fukushima Pref., Japan (福島県伊達郡霊山町)	1993.11.10	10	12972
	Mt. Kobo, Hadano, Kanagawa Pref., Japan (神奈川県秦野市弘法山)	1993.11.10	10	37871
	Sengari-suigenchi, Dojo, Kobe, Hyogo Pref., Japan (兵庫県神戸市道場千刈水源地)	1994.11.24	9	38165
	Kamiya, Himeji, Hyogo Pref., Japan (兵庫県姫路市神谷)	1994.11.24	9	38162

Voucher specimens are deposited in the Herbarium of Kampo & Pharmacognosy Laboratories, Tsumura & Co.

this article, because this species is easily distinguishable from the species in question in the gross rhizome morphology.

Materials and Methods

Sources of plant material used in this study are listed in Table 1. The plant materials were identified from the aerial parts. The rhizomes were dried in an air oven at 30 °C. For critical comparisons transections were cut between two-year-old and three-year-old swollen parts as shown in Fig. 1. Transections were made at about 20 μm thick using a microtome. Sections were stained with aceto-methyl green and observed under a microscope. These methods are identical to those in the previous report (Terabayashi et al. 1997).

The following six characteristics were measured and compared among the species ; 1). diameter of oil cavities, 2). the number of oil cavities per mm^2, 3). ratio of oil cavity area to transection area, 4). ratio of xylem fiber area to xylem area, 5). ratio of rhizomes with phloem fibers to total number of rhizomes in sample, and 6). ratio of rhizomes with cotton-like crystals of hinesol and β-eudesmol to total number of rhizomes in sample. Measurements of 1), 2), 3), and 4) were performed using an image analysis software; Scion Image v.1.62 on PowerMac. 7600.

Results

The following morphological and anatomical features were observed to be common to the rhizomes of *A. koreana* and *A. japonica* (Figs. 2–11).

Rhizomes are creeping, cylindrical, dark grayish brown or blackish brown in color. In a transection a cork layer, 10–40 cells thick, is observed at the outside. Stone cells are inserted in a cork layer or arranged within it. Oil cavities which originate from lysigenous intercellular spaces are distributed in the cortex and pith. Fiber bundles occur just outside of the phloem and in xylem. Scaraliform vessels and reticulate vessels are observed in the xylem. Cotton-like crystals of hinesol and β-eudesmol and crystals of inulin are included in the parenchymatous cells.

Atractylodes koreana is similar to *A. lancea* G1 in the size of oil cavities, the number of oil cavity per mm^2 and a ratio of oil cavity area to transection area (Figs. 12–14). In addition, cotton-like crystals of

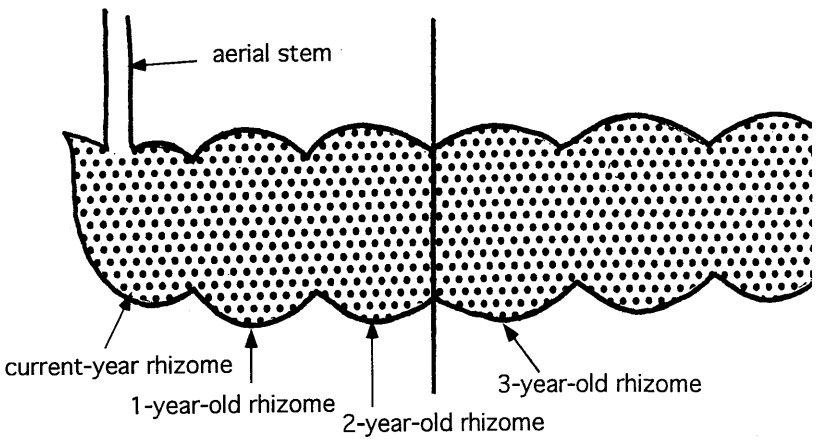
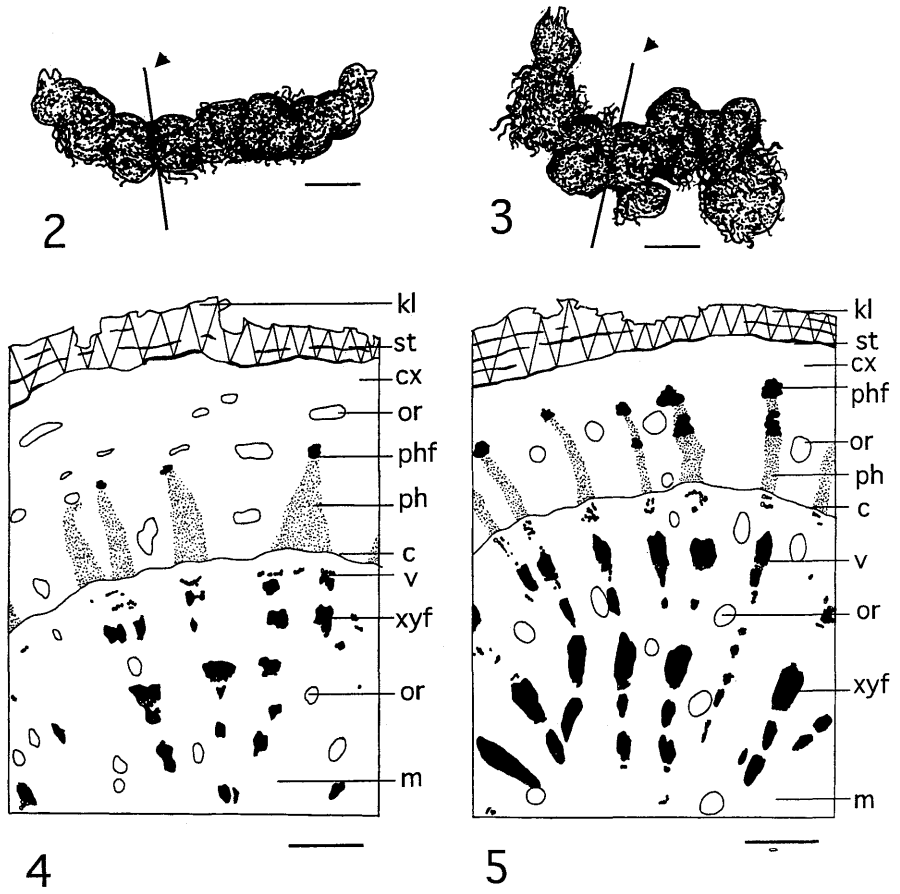
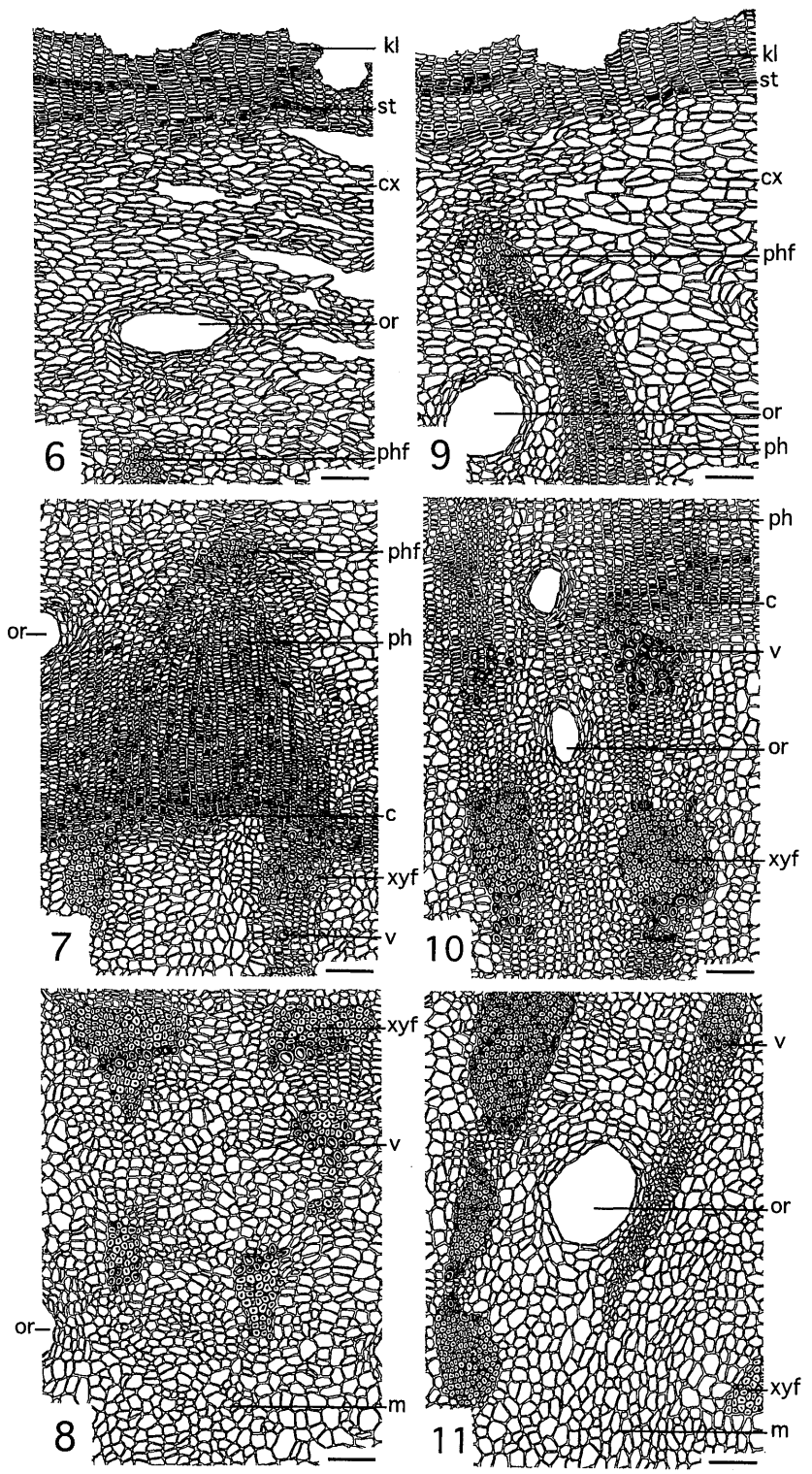


Fig. 1. A diagrammatic illustration of *Atractylodes* rhizome. A vertical bar indicates the position where transections of rhizome are observed.



Figs. 2–5. Rhizomes of *Atractylodes koreana* and *A. japonica*. Figs. 2, 4. *Atractylodes koreana*. Figs. 3, 5. *Atractylodes japonica*. Fig. 2. A sketch of *A. koreana* rhizome, roots are removed. An arrow indicates position where tarnsections were cut and observed. Fig. 3. A sketch of *A. japonica* rhizome, roots are removed. An arrow indicates position where tarnsections were cut and observed. Fig. 4. A diagram of transection of *A. koreana* rhizome. Fig. 5. A diagram of transection of *A. japonica* rhizome. c, cambium. cx, cortex. kl, cork layer. m, pith. or, oil cavity. ph, phloem. phf. phloem fiber. st, stone cell. xyf, xylem fiber. Scale bars: 1cm in Figs. 2, 3, 1 mm in Figs. 4, 5.

Figs. 6–11. Anatomical illustrations of rhizome of *Atractylodes koreana* and *A. japonica*. Figs. 6–8. *Atractylodes koreana*. Figs. 9–11. *Atractylodes japonica*. Figs. 6, 9. Peripheral part of transection of rhizome. Figs. 7, 10. Middle part of transection of rhizome. Figs. 8, 11. Central part of transection of rhizome. c, cambium. cx, cortex. kl, cork layer. m, pith. or, oil cavity. ph, phloem. phf. phloem fiber. st, stone cell. v, vessel. xyf, xylem fiber. Scale bars: 100 μm.


kl
st
cx
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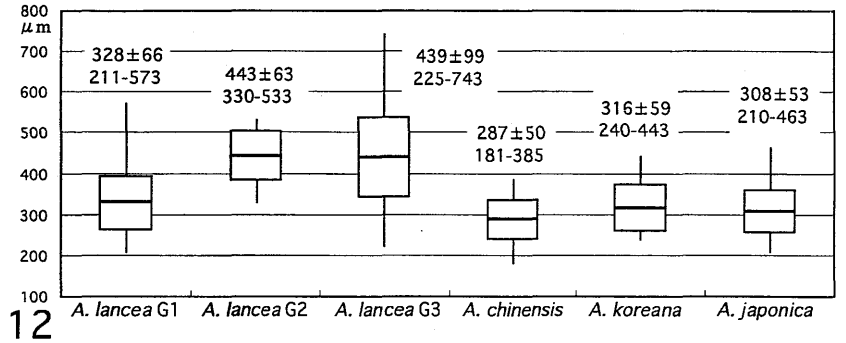
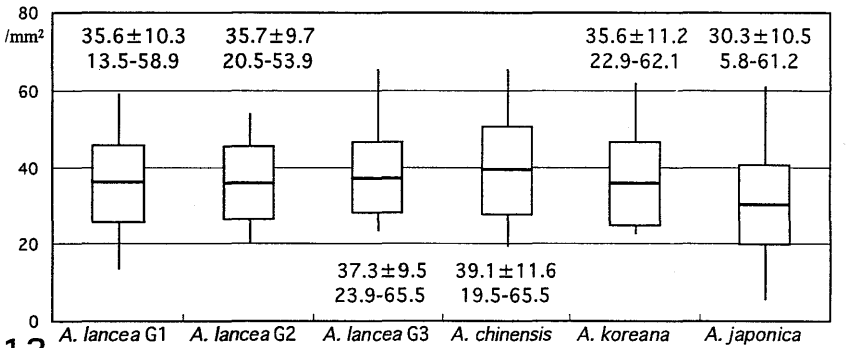
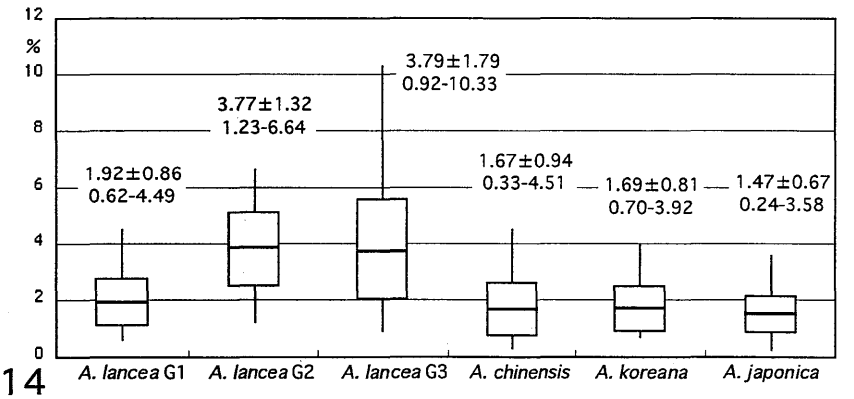

800
μm
700
600
500
400
300
200
100
328±66
211-573
443±63
330-533
439±99
225-743
287±50
181-385
316±59
240-443
308±53
210-463
A. lancea G1
A. lancea G2
A. lancea G3
A. chinensis
A. koreana
A. japonica

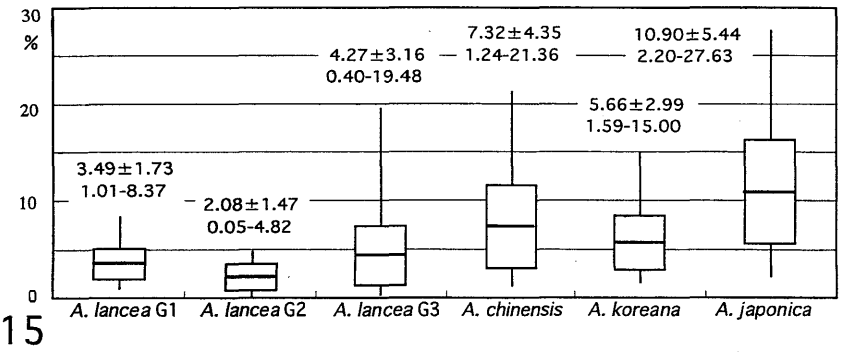
12


80
/mm²
60
40
20
0
35.6±10.3
13.5-58.9
35.7±9.7
20.5-53.9
37.3±9.5
23.9-65.5
39.1±11.6
19.5-65.5
35.6±11.2
22.9-62.1
30.3±10.5
5.8-61.2
A. lancea G1
A. lancea G2
A. lancea G3
A. chinensis
A. koreana
A. japonica

13


12
%
10
8
6
4
2
0
1.92±0.86
0.62-4.49
3.77±1.32
1.23-6.64
3.79±1.79
0.92-10.33
1.67±0.94
0.33-4.51
1.69±0.81
0.70-3.92
1.47±0.67
0.24-3.58
A. lancea G1
A. lancea G2
A. lancea G3
A. chinensis
A. koreana
A. japonica

14


30
%
20
10
0
3.49±1.73
1.01-8.37
2.08±1.47
0.05-4.82
4.27±3.16
0.40-19.48
7.32±4.35
1.24-21.36
5.66±2.99
1.59-15.00
10.90±5.44
2.20-27.63
A. lancea G1
A. lancea G2
A. lancea G3
A. chinensis
A. koreana
A. japonica

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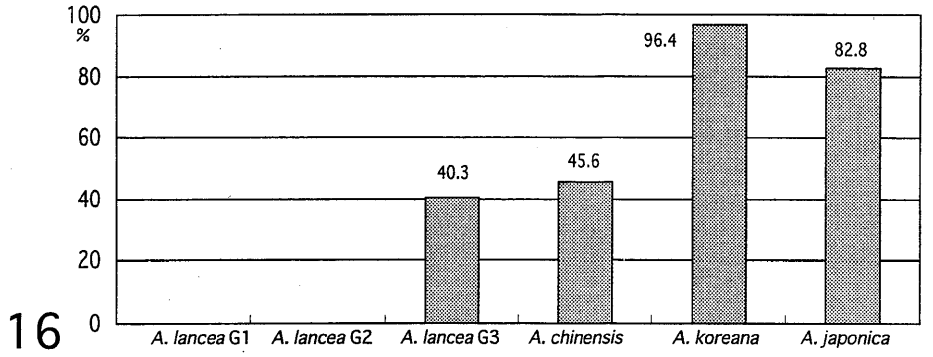
hinesol and β-eudesmol were not or hardly observed in these species (Fig. 17). However, *A. koreana* has much more xylem fibers than *A. lancea* G1, and phloem fibers do not occur in *A. lancea* G1 (Figs. 15, 16).

Compared with *A. lancea* G2, *A. koreana* has smaller oil cavities, much more xylem fibers, and a lower ratio of oil cavity area to transection area (Figs. 12, 14, 15). Differing from *A. koreana*, *A. lancea* G2 does not have phloem fibers but often has cotton-like crystals of hinesol and β-eudesmol (Figs. 16, 17).

Atractylodes koreana is similar to *A. lancea* G3 in the number of oil cavities per mm^2 and the amount of xylem fibers (Figs. 13, 15). *Atractylodes koreana* has smaller oil cavities and a lower ratio of oil cavity area to transection area than *A. lancea* G3 (Figs. 12, 14). The ratio of rhizomes with phloem fibers to total number of rhizomes in sample is much lower in *A. lancea* G3 than in *A.*



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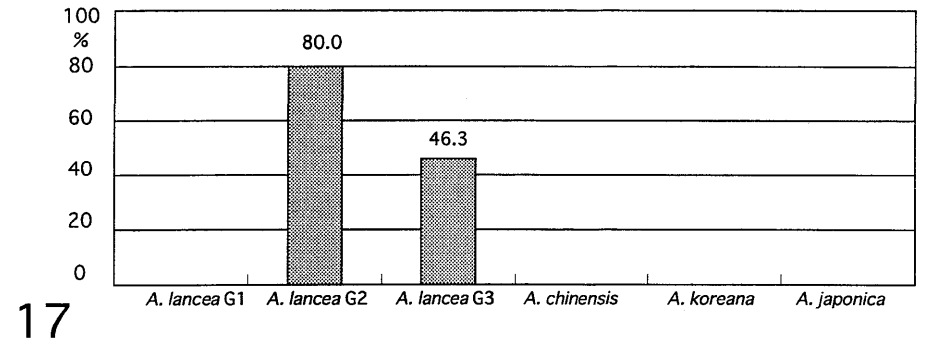

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Figs. 16–17. Measurements of rhizomes of *Atractylodes* species. Fig. 16. Ratio of rhizomes with phloem fibers to total number of rhizomes in sample. Fig. 17. Ratio of rhizomes with cotton-like crystals of essential oil components to total number of rhizomes in sample.

Figs. 12–15. Measurements of rhizomes of *Atractylodes* species. Fig. 12. Diameter of oil cavities. Fig. 13. Number of oil cavities per mm^2 in transections. Fig. 14. Ratio of oil cavity area to transection area. Fig. 15. Ratio of xylem fiber area to xylem area in transections. Horizontal bar : mean. Column : mean ± standard deviation. Vertical bar: min.–max.

koreana (Fig. 16). Furthermore, *A. lancea* G3 sometimes has cotton-like crystals of hinesol and β-eudesmol (Fig. 17).

Atractylodes koreana is comparable with *A. chinensis* in the rhizome anatomy. The difference is that the ratio of rhizomes with phloem fibers to total number of rhizomes in sample is much lower in *A. chinensis* than in *A. koreana* (Fig. 16).

In comparison of *A. japonica* with the three groups of *A. lancea* and *A. chinensis,* nearly the same results were obtained as in *A. koreana. A. koreana* and *A. japonica* are nearly equal in the rhizome anatomy. The only difference is that *A. japonica* tends to have much more xylem fibers than *A. koreana* (Fig. 15).

Discussion

The distribution of *Atractylodes koreana* is restricted to the narrow region of north east China (Shih 1987), and it has little variation of rhizome anatomy. In contrast to *A. koreana, A. japonica* is widely distributed in Japan (except Hokkaido), Korea, North East China and Ussuri (Koyama 1995). In spite of its wide range of distribution the variation of rhizome anatomy is comparatively small and continuous.

Atracty lodes koreana and *A. japonica* are similar in rhizome anatomy. Though they are distinguishable from each other by the morphology of aerial parts (Shih 1987), it is probable that it is difficult to separate material of these species on the basis of rhizome anatomy.

Compared with *A. lancea, A. koreana* and *A. japonica* have smaller oil cavities. This result is in accordance with the previous reports (Takahashi and Maruyama 1961, Takahashi and Namba 1961).

Atractylodes japonica is reported to have the most fibers in the rhizomes among the four species (Takahashi and Maruyama 1961, Takahashi and Namba 1961, Institute of Materia Medica, Chinese Academy of Medicinal Sciences et al. 1979). The present study revealed that *A. japonica* indeed has the most xylem fibers but it has the same amount of phloem fibers as *A. koreana.*

As discussed above, *A. koreana* and *A. japonica* show a different range of variation in rhizome anatomy, when compared with the three groups of *A. lancea.* Consequently the rhizomes of the two species may be distinguished from those of the three groups of *A. lancea* rather accurately. The discrimination of *A. koreana* and *A. japonica* from *A. chinensis* by rhizome anatomy may be not easy, because the difference is only the ratio of rhizomes with phloem fibers to total samples.

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朮類生薬の原植物であるショソウジュツ（*Atractylodes koreana*）とオケラ（*A. japonica*）について，根茎の内部形態を調べ，既に報告したホソバオケラ（*A. lancea*）とシナオケラ（*A. chinensis*）のそれと比較した．比較した形質は，油室の径，油室の個数，油室の面積率，木部繊維の木部に占める面積率（木部繊維の量），師部繊維の出現頻度，綿状結晶析出の有無についてである．ショソウジュツとオケラはこれらの6つの形質において互いに良く似ており両者を区別することは難しかった．ただし，オケラのほうが木部繊維の量が多い傾向を示した．ショソウジュツとオケラはホソバオケラと比較して，油室は小さく，油室の面積率が低く，木部繊維の量が多く，師部繊維の出現頻度は高い傾向を示した．また，綿状結晶の析出は認められなかった．ショソウジュツとオケラはシナオケラに似るが，師部繊維の出現頻度は明らかに高い傾向を示した．以上のことから，ショソウジュツとオケラは，根茎の内部形態において，ホソバオケラからかなり正確に区別できるが，シナオケラとは師部繊維の出現頻度による違いのみで正確な区別は難しいと考えられた．

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